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Investigation of the Effect of Corrosion Rate on Post Welded Heat Treatment of Medium Carbon Steel in Seawater

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Abstract

In this study, the effects of corrosion rate on post welded annealed heat-treated medium carbon steel in seawater was investigated. The medium carbon steel samples were butt-welded by using the Shielded Metal Arc Welding (SMAW) technique and, afterwards, heat treated by annealing at different annealing temperature was carried out. The microstructure of the unwelded and post welded heated samples was characterised by means of optical microscopy. The as received (control), unwelded and post welded annealed medium carbon steel samples were immersed in sea water for a duration of one hundred (100) days, and this was to stimulate the effect on equipment in offshore and food processing applications. Post welded heat treatment on the microstructure, weight loss and corrosion rate were evaluated. The results obtained showed an initial increase in both the weight loss and corrosion rate of samples up to 40 days and started decreasing afterwards. It was equally observed that the post welded annealed samples showed more corrosion activities than the un-welded annealed samples. Above and beyond, corrosion activity was more prominent in samples with the highest annealing temperature. More so, the unwelded annealed medium carbon steel showed a dispersion of coalescence cementite and ferrite grain while the post welded annealed medium carbon steel samples showed a martensite (light area marked by arrows) distributed in the ferrite (dark area) matrix.

Keywords: Medium carbon steel, Corrosion rate, Weight loss, Post welded annealed, Sea water, Microstructure.

1 | Introduction

The use of steel is essential to almost all aspects of human endeavor. Medium carbon steels are generally applied for different usages especially in the oil and gas (onshore and offshore) industries, automobile industries, food processing industries, etc. Therefore, there should be means of influencing and controlling the properties of medium carbon steel materials while in use under corrosive media with a view of improving their performance. Corrosion is responsible for so many mishaps that have occurred in the engineering history of man. The problem with medium carbon steel is that the oxide formed by oxidation does not firmly adhere to the surface of the metal and thus, flakes off easily causing pitting. The two particular reasons for the extraordinary versatility of steel are heat treatment and alloying.

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Heat treatment is an operation involving the heating of the solid metal to a definite temperature followed by cooling at suitable rates in order to obtain certain physical properties which are associated with changes in the nature, form, size and distribution of the micro constituents [1]-[3]. Heat treatment process is widely used to achieve high mechanical properties [4]-[5]. Major requirements of medium carbon steel are high yield strength, high proportional limit, and high fatigue strength. These desirable properties of medium carbon steel can be achieved by adding suitable alloying elements and secondly by heat treatment. Heat treatment is a combination of timed heating and cooling applied to a particular metal or alloy in the solid state in order to produce certain microstructure and desired mechanical properties (hardness, toughness, yield strength, ultimate tensile strength, Young's modulus, percentage elongation and percentage reduction). Annealing, normalizing, hardening and tempering are the most important heat treatments often used to modify the microstructure and mechanical properties of engineering materials particularly steels [6]-[8].

Welding is one of the different processes used in the construction of medium carbon steel to the desired shape. It is a process of joining two or more similar or/and dissimilar metals to achieve complete coalescence [5] and [9]. There are different types of welding which includes Shielded Metal Arc Welding (SMAW), submerge arc welding, gas metal arc welding, plasma arc welding, gas tungsten arc welding, projection welding, and resistance welding [10]. SMAW technique is preferable to the other techniques because of its low cost, flexibility, portability and versatility. When medium carbon steel is welded, it is heated; the heated portion has a microstructure that is different from that of the base metal and is called the Heat Affected Zone (HAZ) [11]. During welding, rapid heating and cooling take place which produce severe thermal cycle near weld line region. Conventional welding processes which rely upon the local melting and fusion of materials generates significant residual stress distribution in the weldment. Post weld heat-treatment is applied to welded steel structures primarily to reduce residual stress and minimize the likelihood of brittle fracture [1] and [11]-[13]. The benefits of post weld heat-treatment include a significant reduction of tensile residual stress in the weld joint and to lesser extent, tempering of the HAZ and the weld metal microstructure. Post Weld Heat Treatment (PWHT) is defined as any heat treatment after welding that often used to improve the properties of a weldment [14].

Medium carbon steel usage is versatile, and several vessels, tank barge, ships, etc., that are used in ocean are produced from medium carbon steel. Sea water offers several corrosion problems due to its process conditions. It is an extremely complex ionic aqueous solution containing at least 70 elements in widely-varying concentrations [15]. It possesses good electrical conductivity (0.04 mΩ cm-1), which is 4,000 times better than freshwater [16]. Salinity, pH, oxygen level, and temperature are parameters that mostly influence its corrosion reactions. Although, the salinity and pH of seawater are relatively stable measurements but temperature and dissolved oxygen may vary. More so, the salinity increased as the depth increased and thus, decreased pH to more acidic. Temperature varies with the amount of sun while oxygen content depends on life forms in seawater. The pH of seawater is usually 7.7-8.3 at the surface, but will decrease and become more acidic (3-4) in deep water as the density increases [17]. Corrosion, like taxes and death is unavoidable particularly in the manufacturing, chemical, and petroleum industries. Hence, if one considers the huge amount of money spent in preventing corrosion and the severe consequences of corrosion disasters, then, this research work is a right step in the right direction. This research work will therefore focus on the investigation of the effect of corrosion rate on post-welded heat treatment of medium carbon steel in seawater.

2 | Materials and Methods

2.1 | Materials and Equipment Used

In this research work, sea water, medium carbon steel, weighing balance, muffle furnace, tong, plastic bowl, lathe machine, shield metal arc welding machine, and sand paper were the materials and equipment used.

2.2 | Determination of the Chemical Composition of Medium Carbon Steel

The chemical composition of the medium carbon steel samples used for this investigation was determined in Petroleum Training Institute, Effurun, Nigeria (*Table 1*).

2.3 | Preparation of Specimen

Pieces of medium carbon steel were purchased from local market in Benin City, Nigeria in the form of rods. The samples of the medium carbon steel were machined using lathe machine into cylindrical pieces of diameter of 14 mm and length of 38 mm. The samples were divided into the following groups:

I. As received (control) medium carbon steel samples.
II. Annealed un-welded medium carbon steel samples at 910^{o}C and 950^{o}C.
III. Post welded annealed medium carbon steel samples at 910^{o}C and 950^{o}C.

2.4 | Welding Process

The welding process was carried out at the Igbinedion University College of Engineering Workshop. A set of 38 mm long and diameter of 14 mm medium carbon steel samples were cut into two halves and one of the edges chamfered. The other edges of the medium carbon steel samples were firmly clamped together with a bench vice while the chamfered edges were brought together giving a root gap of 2 mm. The samples were welded together using the SMAW technique. The welding was done in such a way that the penetration of the weld was achieved to the thickness level of the medium carbon steel. The covering slag was machined out using lathe machine.

2.5 | Annealing Process

The un-welded and welded medium carbon steel samples were annealed at a temperature of 910^{o}C and 950^{o}C and soaked for a duration of one hour (60 minutes) in a switch off muffle furnace.

2.6 | Determination of Weight Loss and Corrosion Rate

The prepared medium carbon steel samples and seawater were used for the experimental determination of the corrosion rate of the medium carbon steel at room temperature. Six plastic bowls were filled with seawater and labeled A to F. The various steel samples were weighed with an electronic precision weighing balance and recorded as (W_1) before being immersed into their respective labeled plastic bowls. After ten days interval, the samples were weighed to determine weight loss and this lasted for duration of two months (100 days). The new weights are recorded as final weight (W_2). *Eq. (1)* was used to calculate the corrosion rate of medium carbon steel.

$$W_L = W_i - W_f. \quad (1)$$

Eq. (2) was used to calculate the corrosion rate of medium carbon steel.

$$C_R = \frac{87.6W_L}{DAT}. \quad (2)$$

Where,

C_R = Corrosion Rate (mm/y).

W = Weight loss (mg).

W_L = Weight loss.

W_I = Initial weight.

W_F = Final weight.

D = Density of medium Carbon Steel.

A = Area of medium carbon steel samples used.

T = Exposure time to sea water (days).

3 | Results and Discussion

Table 1 shows the results of chemical composition of the medium carbon steel sample (wt. %) used in this research work. From the analysis, it was revealed that the percentage composition of carbon in the steel was 0.35%. According to Onyekpe [18], medium carbon steel has percentage composition of carbon by weight within the range of 0.25-0.5% weight carbon.

Table 1. Chemical composition of the medium carbon steel sample (wt. %).

S/N	Element Present	Percentage Weight (%)
1	Carbon (C)	0.35
2	Silicon (Si)	0.31
3	Manganese (Mn)	0.95
4	Phosphorous (P)	0.045
5	Sulphur (S)	0.037
6	Titanium (Ti)	0.021
7	Copper (Cu)	0.432
8	Nickel (Ni)	0.044
9	Chromium (Cr)	0.071
10	Molybdenum (Mo)	0.005
11	Vanadium (V)	0.002
12	Aluminium (Al)	0.025
13	Tungsten (W)	0.005
14	Niobium (Nb)	0.013
15	Nitrogen (N)	0.006

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Table 2 shows chemical composition of sea water used. One of the important characteristics of aqueous solutions with respect to corrosion is the conductivity of the solution. A solution of either alkaline or acidic state will enhance corrosion. However, a neutral solution will have a very low tendency of corrosion and if there must be corrosion, it will be slow unlike sea water. Since the pH is not neutral, thus, the sea water collected is very much okay for the research work.

Table 2. Chemical composition of sea water used.

S/N	Parameters	Results
1	pH	7.43
2	Conductivity, μs/cm	894
3	TDS, mg/l	447
4	Total alkalinity, mg/l	1.66
5	Chloride, mg/l	2677.5
6	Sulphate, mg/l	293
7	Nitrate, mg/l	< 0.01
8	Phosphate, mg/l	0.07
9	Salinity, mg/l	2988

Fig. 1 and *Fig. 2* show the evaluation of corrosion rate against exposure time for un-welded annealed and post welded annealed medium carbon steel. In each analysis, the control setup (as received) was not annealed while the rest samples were annealed at 910°C and 950°C, respectively. The results revealed a speedy increase in corrosion rate for the first 40 days with peak at the 40^{th} day and this was followed by

a slow corrosion rate from 40th day to 100th day. The sudden drop in corrosion rate for both post welded annealed and un-welded annealed medium carbon steel can be credited to the aggressiveness of the chemical reactivity's, transport properties of the environment which is stagnant, and the temperature of the corrosion medium. This resulted in the formation of reddish-brown colouration that forms a protective layer that interact with the medium carbon steel and its environment [4]. Furthermore, it was observed that the control samples that were neither post-welded nor annealed show better corrosion resistance tendency. However, corrosion rate increases with increased in annealing temperature in both un-welded and post welded with highest corrosion rate recorded at annealing temperature of 950°C which was the highest used in this project work. These findings agree with the research work of Oyejide et al. [19]. Their findings reveal that annealed samples of medium carbon steel at a temperature of 1000°C experience higher corrosion rate in comparison to annealed samples at 930°C and as received samples (not annealed) that served as control setup. They concluded that, corrosion rate increases with increased annealing temperature. They attribute their findings to increase in grain size and relatively segregation of the grains with increasing temperature.

Moreover, grain growth with increasing temperature brings about changes in cathodic to anodic area ratios with regards to the phases present, thus susceptibility to corrosion. Also, the driving force for corrosion in aqueous media such as sea water is due to the difference in potential of small area which results to the heterogeneities in the used material, which is also a function of factors such as defects in crystal structure of the metal/alloy, segregation of element or phase. Also, when steels are heated to temperature above 920°C, they have their carbides dissolve into the matrix of the steel to form solid solution alloys. When they are cooled slowly as obtained in the furnace annealing of the medium carbon steel samples, they experience quasi-statistically. This condition brings about carbide segregation at the grain boundaries of the HAZ regions. Conversely, in the presence of seawater which is a corrosion environment, intergranular corrosion occurs leading to the dissolution of Iron (Fe) in the affected region around the grain boundary. Subsequently, as a result of highly localized of this region compared to the bulk of the medium carbon steel, which serves as the cathode region, the corrosion rate will be high because of the unfavoured low anode to cathode area ratio. Thus, the reason for the high corrosion rate recorded in the annealed post welded samples unlike the annealed un-welded samples.

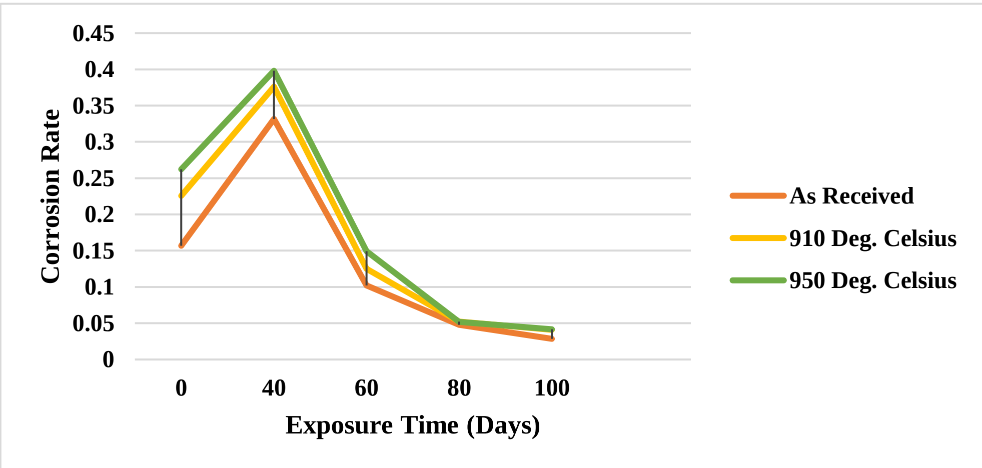

Fig. 1. Corrosion rate against exposure time for un-welded annealed medium carbon steel.

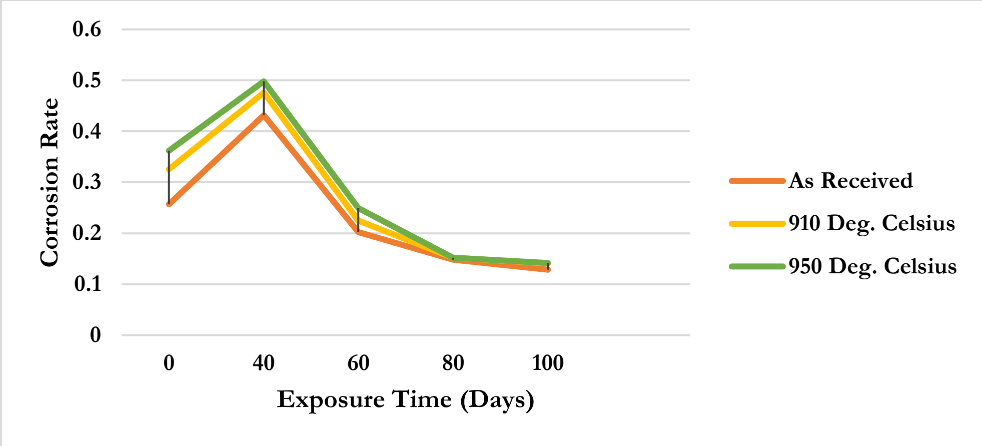

Fig. 2. Corrosion rate against exposure time for post welded annealed medium carbon steel.

Fig. 3 and *Fig. 4* show the evaluation of weight loss against exposure time. There was a progressive weight loss for all samples. However, weight loss was more severe with the annealed post welded samples (*Fig. 4*) unlike annealed unwelded samples (*Fig. 3*). The rate of weight loss by all samples were high in first 40 days. However, after 40 days, the rate of weight loss was slow and steady.

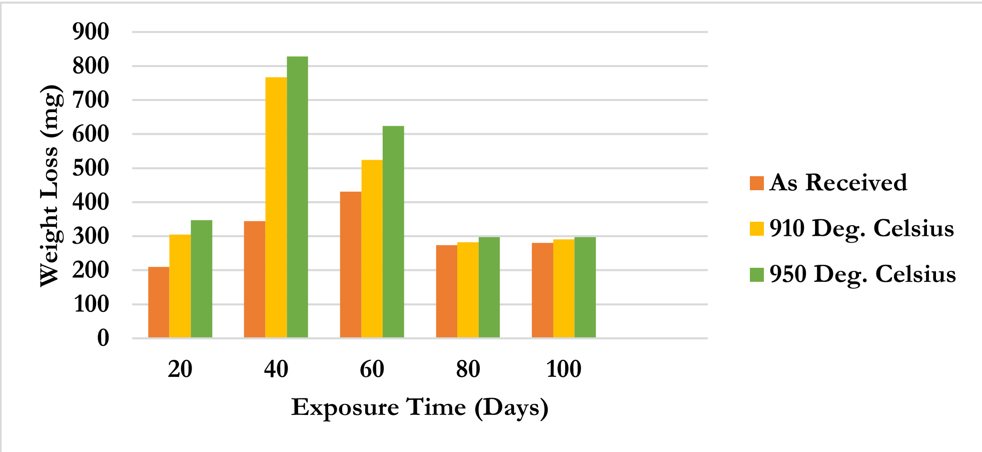

Fig. 3. Weight loss against exposure time for un-welded annealed medium carbon steel.

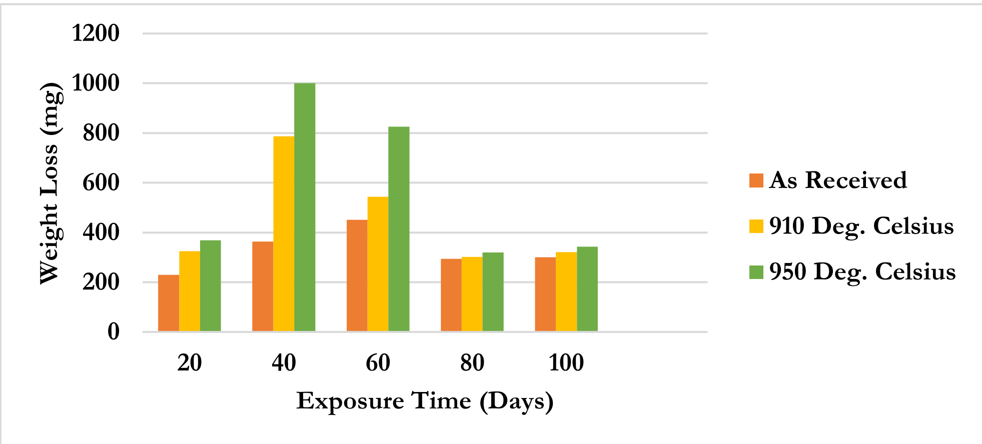

Fig. 4. Weight loss against exposure time for post welded medium carbon steel.

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The results of microstructural analyses carried out on the three different sets of samples using an optical microscope showed that the control samples (as received) medium carbon samples possess fine dispersion of coalesced pearlite and ferrite grain as presented in *Fig. 5*.

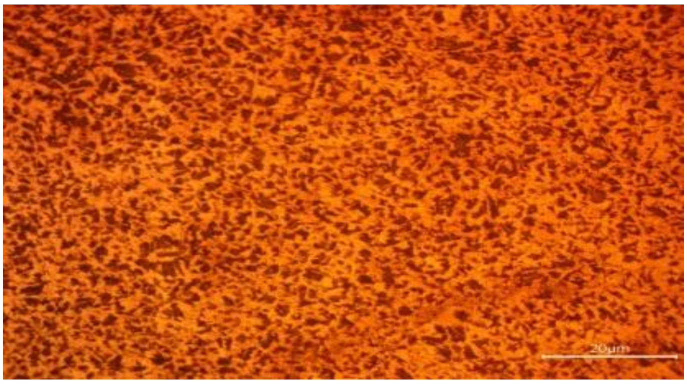

Fig. 5. Microstructural of as received sample.

Furthermore, the unwelded annealed medium carbon steel showed a dispersion of coalescence cementite and ferrite grain as depicted in *Fig. 6* while the post welded annealed medium carbon steel samples showed a martensite (light area marked by arrows) distributed in the ferrite (dark area) matrix as shown in *Fig. 7*.

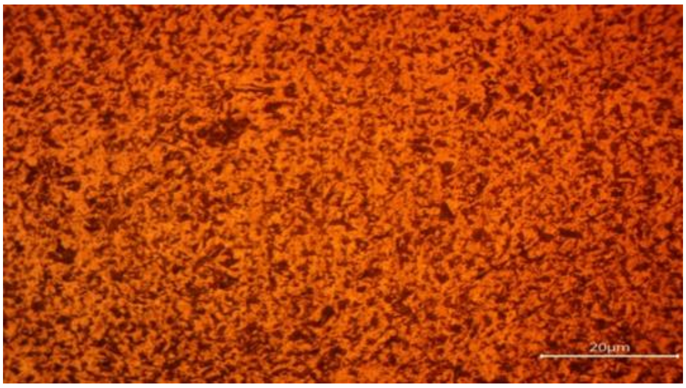

Fig. 6. Microstructural of unwelded annealed medium carbon steel.

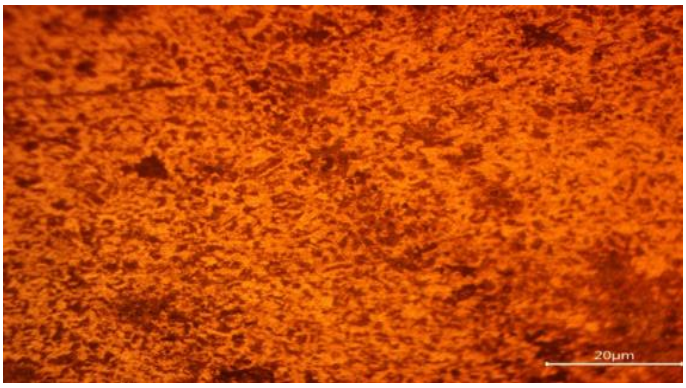

Fig. 7 Microstructural of post welded annealed medium carbon steel.

4 | Conclusion

Based on what mentioned above, it was concluded that

I. Annealed post welded, and annealed un-welded medium carbon steel samples experienced rapid corrosion rate at the early stage of exposure to seawater, and as the process continued, decrease in corrosion rate occurred.
II. In this research work, the samples with the highest annealing temperature of 9500°C were more susceptible to corrosion rate. Thus, it can be deduced that annealing temperature play massive effect on corrosion rate of medium carbon steel.
III. Unlike the post welded and unwelded annealed samples, the control samples that was neither post welded nor annealed showed better corrosion resistance. Therefore, if it is only for the purpose of corrosion resistance, annealing and welding may not be required. However, if annealing is necessary, then it must be carried out at a lower temperature.

Conflicts of Interest

The authors declare no competing interest.

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